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REPORT 1700
AERO REPORT 1049

NAVY DEPARTMENT

THE DAVID W. TAYLOR MODEL BASIN

AERODYNAMICS LABORATORY

WASHINGTON 7, D.C.

PHASE II TETHERED TESTS AND LOW-SPEED FREE FLIGHT TESTS OF GEM III

by

Arthur E. Johnson

December 1962

SYMBOLS

S	base area in square feet, measured to outer edge of nozzle
C	perimeter of the base in feet, measured at outer edge of nozzle
b	length of base in feet, measured to outer edge of nozzle
a	width of base in feet, measured to outer edge of nozzle
β_v	collective vane deflection in degrees (see Figure 1) (positive deflection is with trailing edges deflected rearward, to produce forward thrust)
$\beta_{v_{N=0}}$	collective vane deflection with neutral yaw control (obtained by putting foot pedals in neutral position while keeping collective vane control lever locked)
h	height above surface (in feet, unless indicated otherwise), measured at center of base to plane containing the lower edges of the nozzle
L	total lift in pounds
y_f	extension of flap trailing edge in inches, measured perpendicular to inner wall of nozzle
N	yawing moment in pound-feet
M	pitching moment in pound-feet
$\mathcal{L}$	rolling moment in pound-feet
γ_{max}	gradient in degrees of steepest slope above which vehicle can hover
ψ	yaw angle in degrees that vehicle assumes while approaching slope (e.g. $\psi = 90^\circ$ implies sideways motion up slope)
R	radius of curvature of flight path, in feet
V	velocity of vehicle in feet per second
g	unit of acceleration (1 g = 32.2 ft/sec^2)
a_{lat}	lateral acceleration in g's

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SUMMARY

Second-phase tests of the Marine Corps GEM III vehicle were made in order to evaluate the effectiveness of a modified control system and to determine handling characteristics in free flight.

Results of tethered tests showed that effectiveness of the modified controls was adequate for untethered flights. Untethered tests then showed that maximum velocity was 27.4 feet per second; that the maximum slope which GEM III could climb (or above which it could hover) was a 9 percent grade; and that lateral acceleration in turns with full thrust was about the same as for hovering above a slope, but varied slightly with turn radius.

Following free flight tests, a reversible pitch shrouded propeller-engine unit was installed on the vehicle to increase propulsive and braking thrust for additional tests at Langley Research Center.

INTRODUCTION

GEM III is a one-ton experimental manned ground effect machine constructed for the Marine Corps by National Research Associates, Incorporated. First tests of this vehicle were performed in a static test rig at the David Taylor Model Basin. Results of these first tests, in which pitch and roll controls were found to be completely ineffective, were published in Reference 1. Reference 1 also recommended that several modifications be made to the control system in order to make free flight possible. Therefore, at the request of the Marine Corps (Reference 2), the controls were modified, as described herein, and additional tests were made. The purposes of the second group of tests were to determine the effects of changes in the control system and to evaluate certain low-speed maneuvering characteristics.

It was desired that the data from these tests would be sufficient to predict GEM III's ability to perform basic flight movements. It was not expected, however, that this investigation would be an exhaustive and definitive study of desirable flying qualities for a class of ground effect machines. Standards by which to judge GEM flying qualities are still lacking. For this reason the Langley Research Center of the National Aeronautics and Space Administration, with a view toward establishing such criteria, requested the use of GEM III for a program of tests. For its work, Langley required the addition of a reversible thrust propulsion unit on the vehicle. Accordingly, the Marine Corps requested DTMB to design and install the propulsion unit prior to shipment of GEM III to Langley (Reference 3). A description of that installation is included in this report.

VEHICLE MODIFICATIONS

A description of the basic vehicle is contained in the report of first phase tests (Reference 1). Figure 1 is a sketch of the modified vehicle showing principal dimensions. Figure 2 is a photograph of the vehicle. Modifications were as follows:

CONTROL SYSTEM

The original variable-camber vanes in the main nozzle were retained and twelve new vanes were added in spaces at the vehicle corners. Also added were sheet metal guides, of L-shaped cross section 1/4 x 1/4 x .020

inch, that were bent to match the shape of the variable-camber vanes when deflected for maximum propulsive thrust. The guides were riveted to the inner and outer walls of the main nozzle so as to form seals between the walls and the edges of the vanes when at maximum angle. Maximum angle for Phase I tests had been 45°, and, following a recommendation of Reference 1, it had been planned to allow for a deflection greater than 45° in the Phase II tests in order to provide greater thrust. However, breakage of the flexible vane material made it necessary to reduce maximum deflection to 37° for the Phase II tests. The sheet metal seals were therefore installed to match the vane contours at this angle. It was hoped that increased vane effectiveness due to the seals would compensate for the reduced angle.

As before, thrust control (propulsion and braking) and yaw control were achieved by deflecting the variable-camber vanes collectively and differentially, respectively. However, the cockpit controls for the vanes were changed. The control wheel was removed and a hand lever and foot pedals were installed. Movement of the pedals moved the control vanes differentially, the sense of the resulting yawing moment being as with ordinary aircraft rudder pedals. The hand lever was fitted with a catch to hold it in neutral, or in one of four forward-thrust positions, or in one rearward-thrust position. The lever produced collective deflection of the main nozzle vanes except when partially overridden in extreme position by foot pedals.

For pitch and roll control, the old dump-valve system was replaced with a system of spoiler-flaps in the main nozzle below the variable-camber vanes. One flap was placed in each of the straight sections of the main nozzle. The flaps were hinged at their upper edges and normally lay against the inner wall of the main nozzle, held there by springs. They were moved by cables attached to an aircraft-style control stick in the cockpit. Stick movement produced pitching and rolling moments as in an ordinary airplane by pulling appropriate flaps into the airstream in the main nozzle, partially spoiling the flow. For example, movement of the control stick to the right extended the flap in the nozzle section on the right-hand side of the vehicle while all other flaps remained unextended. The flaps in the two forward nozzle sections acted together for nose-down moment and the flaps in the two rear nozzle sections acted together for tail-down moment.

During untethered flights, the pilot reported that the vehicle responded rather slowly to control stick movements. In an effort to improve the response, the spoiler flaps were adjusted so that when the control stick was in the neutral position, all the flaps trailing edges extended 1.3 inches from the nozzle wall rather than lying flat against the wall. Consequently, stick movement not only extended one flap, but also allowed the opposite flap to retract further. The pilot reported that this change produced a comforting improvement in response, and all other untethered flights were made with this adjustment.

BULKHEAD OPENING

The original vehicle had a sheet metal bulkhead separating the plenum into right and left halves. Thus, each fan only supplied air to nozzle sections on one side of the vehicle. For Phase II tests a large opening, of 7 square feet area, was made in the bulkhead to equalize pressure in the right and left plenums. This was done in accordance with a recommendation of Reference 1 for the purpose of reducing random disturbances in the roll mode.

COCKPIT ARMOR

For Phase I tests, a temporary pilot's seat had been placed to the rear of the plane of the lift fans, outside the danger zone, in case either fan should fracture. For Phase II tests, the pilot's seat was replaced in the cockpit and armor plate, made of 2024 T-4 aluminum alloy one-half inch thick, was installed around the cockpit. The armor was placed in such a way that all pieces lay in fore-aft planes in order to minimize drag. The plates were cut so that, in case of fan failure, no fragment would be able to go in a direct path from any point in either fan disk to any point on the pilot.

FINS AND ENGINE FAIRINGS

In preparation for free flight testing it was necessary to provide fine-mesh air intake screens for the engines, as specified by the engine manufacturer. At the same time, it was desirable to make faired engine enclosures to reduce drag, and to provide some lateral area as far aft as possible to decrease expected directional instability. Hence, engine fairings were installed, each of which extended the nacelle contours aft to the engine exhausts. Each fairing supported a triangular vertical fin and had inlet openings covered with screen.

PROPULSION UNIT

For added propulsion a ducted propeller was designed and installed between the existing nacelles. It was powered by a YT62-S-2 Solar Titan gas turbine engine. This is the same type used for the lift fans, except that the propulsion engine must be run either at idle speed (50 percent rated speed) with no load, or at rated speed, which is 4040 rpm. The propeller was coupled directly to the engine output shaft without gearing or clutch.

The engine was mounted as close behind the propeller as possible, allowing room for a propeller shaft with two bearings. Engine, propeller shaft, and bearings were enclosed by a cylindrical fairing 15 inches in diameter which had engine air intake openings covered with fine-mesh screen. There was a 15-inch diameter hemispherical nose fairing just in front of the propeller. The hub itself and the blade shanks were not faired, but they were within the 15-inch diameter space between the nose fairing and the engine fairing.

The propeller had four untapered and untwisted blades using the NACA 0010 airfoil. Blade pitch was controlled by a reversible electric motor mounted inside the propeller hub. The blade-pitch control switch was mounted on the throttle lever for the propulsion engine. Nominal diameter of both propeller and shroud was 35 inches. The shroud was recessed near the propeller to obviate the difficulty of holding a close tip clearance (see Figure 1).

The shroud inlet, made of fiberglass-plastic 1/16-inch thick, was a body of revolution trimmed to fit the irregular space between the two main nacelles. The shroud exit was a straight transition from the 35-inch diameter circle to a square approximately 38 inches on a side.

TEST PROCEDURE

TETHERED TESTS

Following completion of modifications involving the vanes, spoiler flaps, cockpit armor, and bulkhead, tests to determine control effectiveness were made using the static test rig described in Reference 1. Controls were set in fractional steps throughout their ranges and forces and moments were measured with the model held stationary.

FREE FLIGHT TESTS

After installation of fins and engine fairings, but before installation of the propulsion unit, untethered tests were made at lo speeds to determine maximum speed and lateral acceleration. Maximum speed was measured by flying over a straight course 700 feet long on a day when the wind was nearly calm. Numerous passes were made in both directions and the results averaged. On each pass the vehicle started from rest and accelerated at full thrust for 400 feet. The time to cover the last 100 feet of this distance was measured. The vehicle decelerated in the last 300 feet, which was ample distance for stopping.

Lateral acceleration was determined in two different flight conditions. The first was hovering over sloping ground, and the second was flying at full speed in circles. For the first, the steepest slope over which the vehicle could hover with wind calm was measured. For the second, the vehicle was flown at full thrust as fast as possible in circles of various diameters. The course was marked to show radius and azimuth and speeds were calculated by analyzing motion pictures taken from a helicopter flying overhead.

WATER TEST

In addition to the low-speed tests over ground, a brief flight was made in the TMB's maneuvering and seakeeping facility to confirm that the vehicle would float stably and that it could be operated over water. Motion pictures were made; however, no quantitative data were taken.

RESULTS AND DISCUSSION

CONTROL EFFECTIVENESS

The effects of control modifications upon propulsion and attitude control are shown in Figures 3 through 9.

Figure 3 presents the effectiveness of the variable-camber vanes in producing thrust when deflected collectively. The propulsive thrust includes an estimated 24 pounds of engine exhaust thrust. For comparison, vane effectiveness before modifications (from Reference 1) is shown with a dashed curve. It may be seen that positive vane deflection produced about the same propulsive thrust after modification with 37° deflection as was obtained before modification with 45° deflection. The trend of the curve suggests that the sheet metal seals and the extra vanes may have effected a significant improvement in thrust if higher vane deflections had been possible. However, for braking, only about three-fourths as much longitudinal force was available from the vanes. The decrease is evidently due to the sheet metal seals, which act to spoil the flow when the vanes are at any angle other than full positive deflection.

Hover height, as affected by vane deflection, is shown in Figure 4. After modifications, hover height was about 13 inches both with undeflected vanes and with vanes deflected 20°. This height compares with 14 inches with no deflection and about 12 inches for 20° deflection before modifications (Reference 1).

Yawing moment available is presented in Figure 5. The absolute value of the yawing moment parameter obtained with full right or full left "rudder" pedal movement is plotted against propulsion-vane setting, that is, the collective setting which the vanes would have if the pedals were in the neutral position. At the higher positive collective settings of the vanes, any attempt to superpose differential vane deflection by actuating the yaw control has the effect of deflecting vanes on one side of the vehicle only a small additional angle, up to maximum deflection. The resulting decrease in available differential deflection partially accounts for the decrease in available yawing moment. The fact that the vanes are less effective, per degree of deflection, at the higher angles also contributes to the decrease in available yawing moment. These two decreasing effects are also present with negative collective vane settings, but it is in this region that the spoiler effect of the vane-edge seals is most harmful. Hence the more rapid loss of yawing power at negative thrust control settings.

Because of the limit imposed on maximum vane deflection by the vane breakage problem, no advantage has resulted from modifications to the vanes. Disadvantages have been realized, though, in the loss of braking force and in the loss of available yawing moment. Therefore it is recommended that the vane-edge seals be removed.

Effectiveness of the flaps in producing pitch control and roll control is presented in Figures 6 and 7, respectively. The effect of pitch control and roll control on hover height is shown in Figures 8 and 9, respectively. It can be seen that there is no significant loss in hover height either with pitch control or with roll control. This was expected because of the small loss of height experienced in the simulated jet spoiler roll control test of Reference 1.

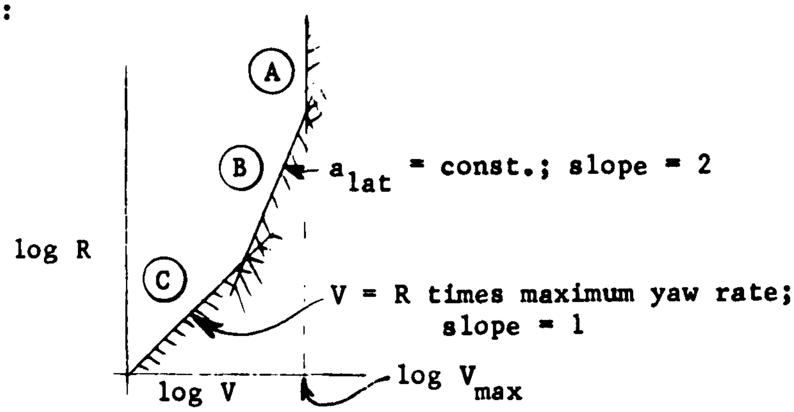
FREE FLIGHT CHARACTERISTICS

Maximum velocity in a straight course was found to be 27.4 feet per second, using both full vane deflection and maximum nose down pitch angle. This result was the average of 20 pairs of measurements, each pair consisting of an upwind and a downwind observation. An analysis shows that the speed attained after accelerating for 400 feet was within one foot per second of the speed attainable on an unlimited course.

Hill climbing ability of GEM III at very low speeds (essentially hovering) is shown in Figure 10. It will be seen that the steepest slope the vehicle can climb, a 9 percent grade, must be approached with a yaw angle of 45° or more. This slope represents a lateral acceleration of 0.09 g.

Lateral acceleration in steady state turning maneuvers with full thrust is shown in Figure 11, which presents the relationship of lateral acceleration, speed, and turn radius. Lateral acceleration varied between 0.074 g, in the largest turn measured, and 0.119 g, in the smallest turn measured. These turns were made at the highest speed possible with maximum thrust. The desired turn radius was attempted first by applying roll control. If the desired radius was not achieved with full roll control, yaw control was added until the turn radius was achieved with some sideslip.

Speed in a turn, then, is conceived to be limited by one or more of three characteristics, depending on radius, as indicated in the following sketch:



In very large turns (region "A" of the sketch) the speed is limited by propulsive thrust, just as straight line speed is. In region "B" the limit line is established by the maximum lateral force that can be brought to bear; and in region "C" the speed is limited by the maximum yaw rate attainable.

CONCLUSIONS

A modified attitude control system, incorporating jet spoilers in the main nozzle, was installed in GEM III pursuant to a conclusion of earlier tethered tests that control with the original system would be inadequate for free flight tests. Additional tethered tests showed the new controls to be adequate for untethered flights at low speed.

The system of variable-camber vanes in the main nozzle was also modified by adding 12 new vanes and by providing seals against which the vanes' edges would seat when deflected for maximum propulsion. These seals were found to provide no appreciable improvement in propulsion, but caused a loss of braking force and a loss of available yawing moment at extreme vane deflections. Removal of the seals is therefore recommended.

Other modifications made prior to untethered flights include new cockpit controls resembling those of ordinary aircraft, cockpit armor plate to protect the pilot in case of failure of the lift fans, provision of ventilating holes between right and left plenums, and streamlined engine fairings with vertical fins.

Free flight handling tests revealed that GEM III had a maximum speed of 27.4 feet per second in a straight course; that she could climb a 9 percent grade; and that she had lateral accelerations in full thrust turns varying from 0.074 g in large turns to 0.119 g in small turns.

GEM III was found to be operable over water, but no water operation data were taken.

A separate propulsion unit consisting of a 35-inch diameter reversible pitch, shrouded propeller driven by a Solar Titan YT62-S-2 engine was installed. Its purpose was to provide additional thrust for further handling tests to be performed at Langley Research Center.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
December 1962

REFERENCES

1. Johnson, Arthur E. and Harvey R. Chaplin. Results of GEM III Tethered Tests. Wash., Aug 1961. 20 p. incl. illus. (David Taylor Model Basin. Rpt. 1546. Aero Rpt. 1012)
2. USMC P.O. No. 1-0018, Ammendment No. 2, of 30 Apr 1961.
3. USMC P.O. No. 2-0014 of 22 Sep 1961.

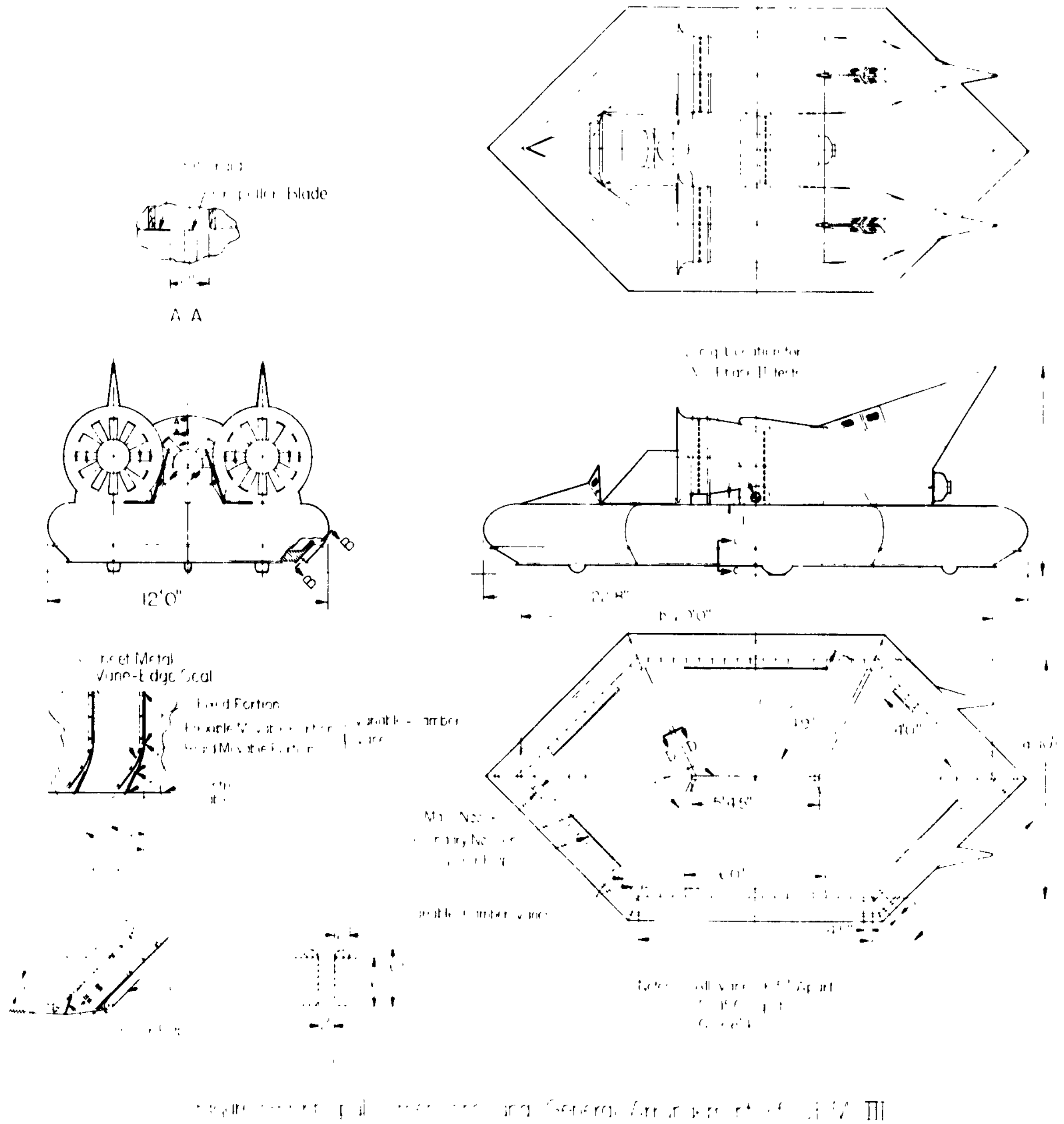

Blade
A A
12'0"
Sheet Metal
Vane-Edge Seal
Fixed Portion

Figure 2 - Photograph of GEM III During Handling Tests

PSD-304,265

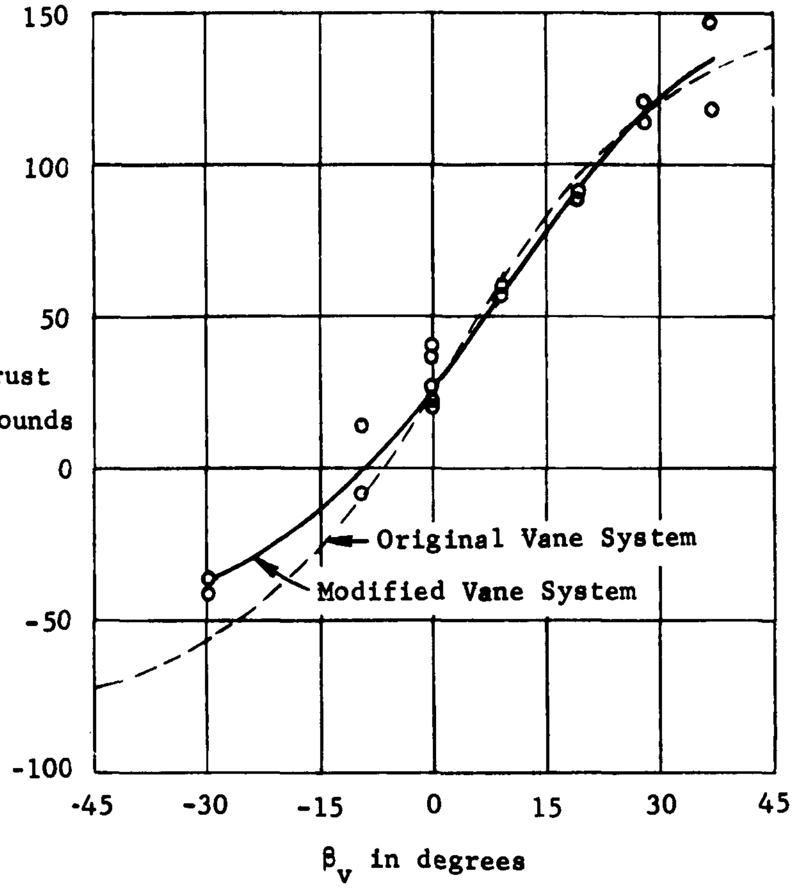


Figure 3 - Propulsive Thrust Produced by Collective Vane Deflection

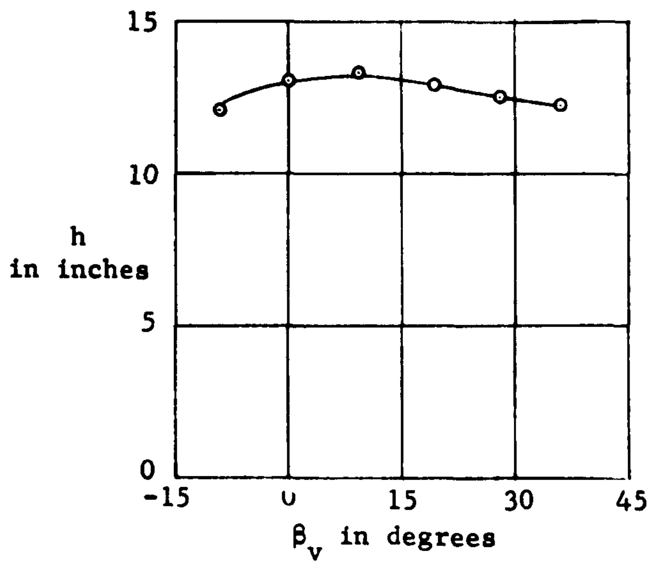


Figure 4 - Effect of Collective Vane Deflection on Hover Height

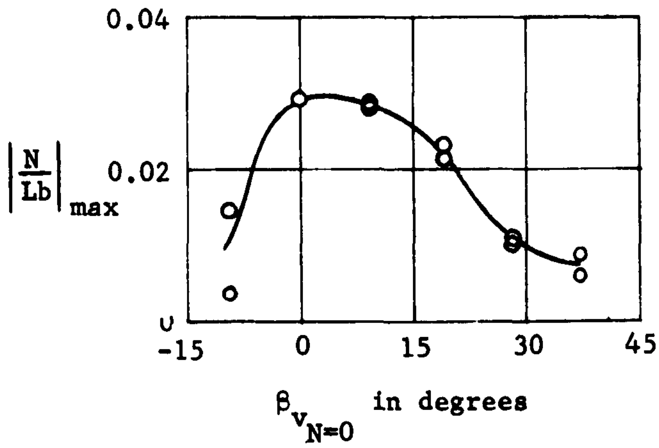


Figure 5 - Yawing Moment Available With Various Collective Vane Settings

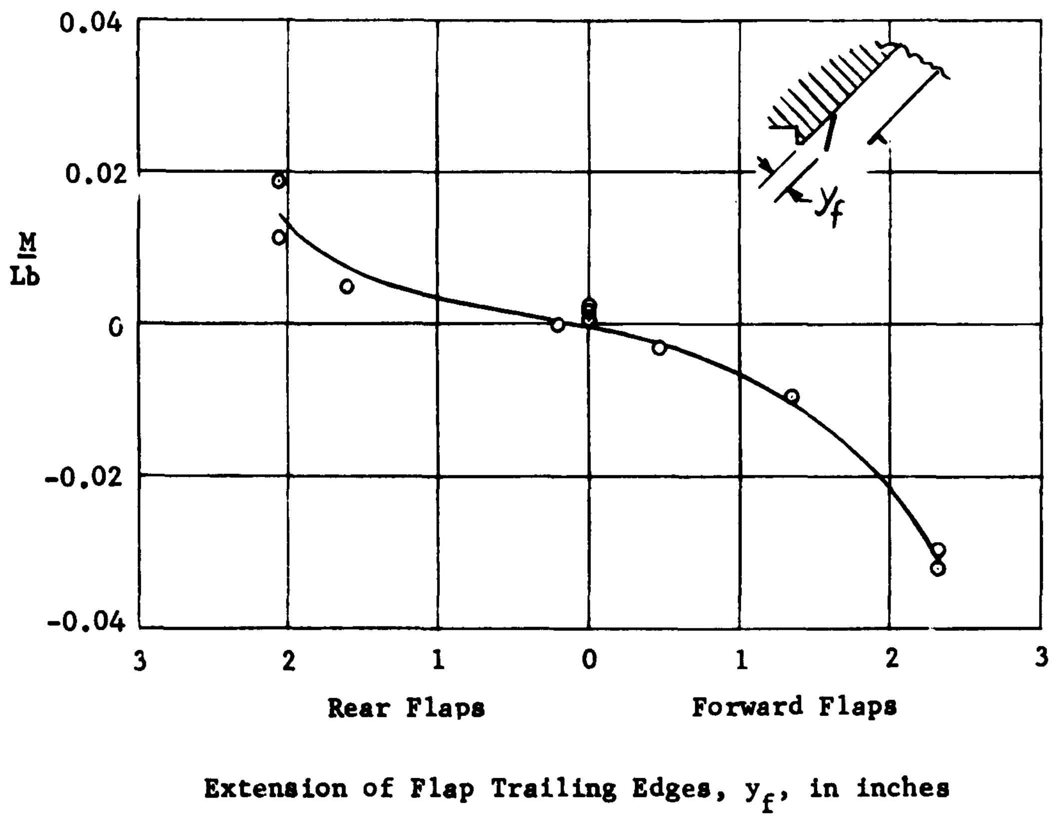
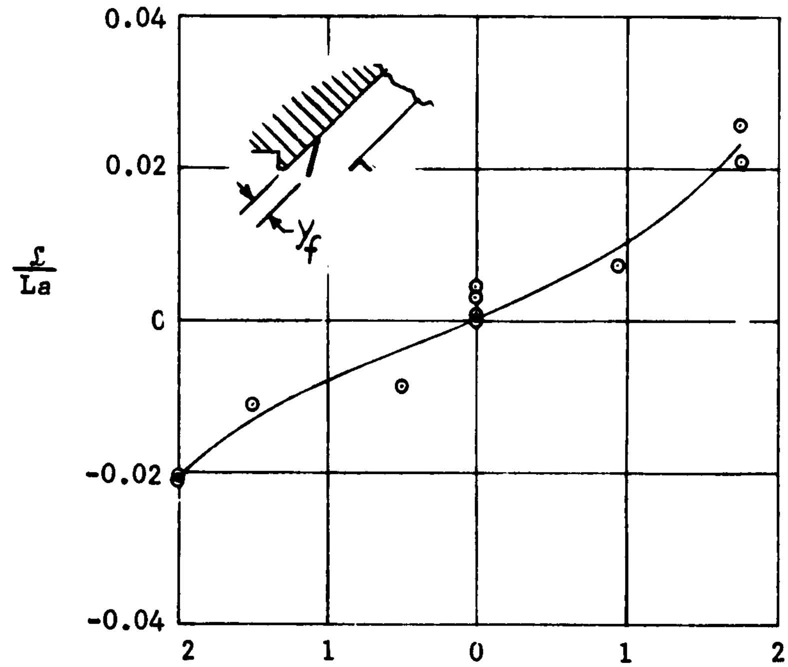


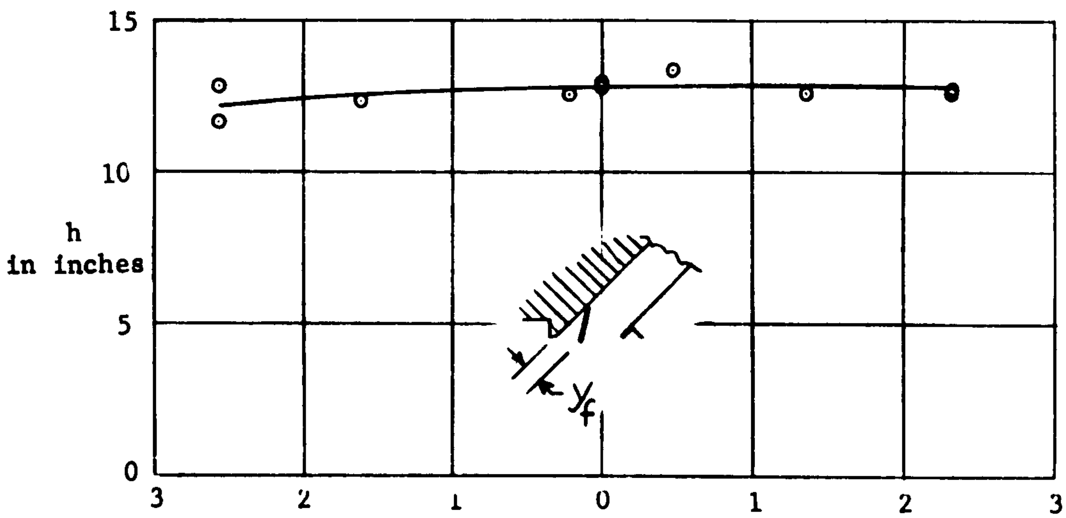
Figure 6 - Pitch Control Effectiveness



Left Flap Right Flap

Extension of Flap Trailing Edge, y_f, in inches

Figure 7 - Roll Control Effectiveness



Rear Flaps Forward Flaps

Extension of Flap Trailing Edges, y_f, in inches

Figure 8 - Effect of Pitch Control on Hover Height

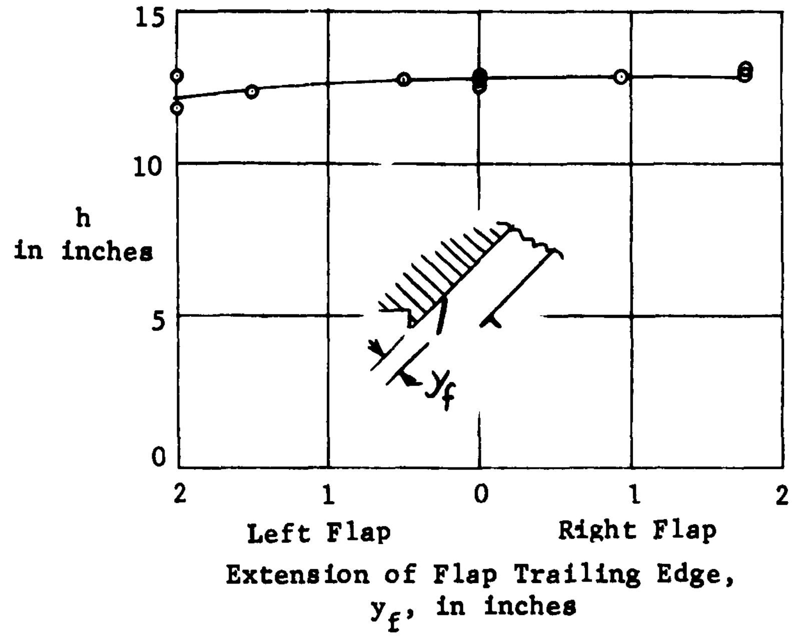


Figure 9 - Effect of Roll Control on Hover Height

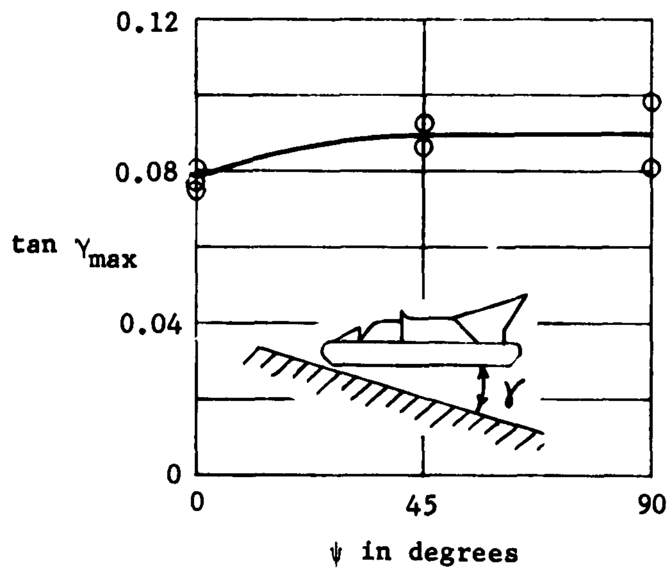


Figure 10 - Effect of Yaw Angle on Maximum Angle of Climb

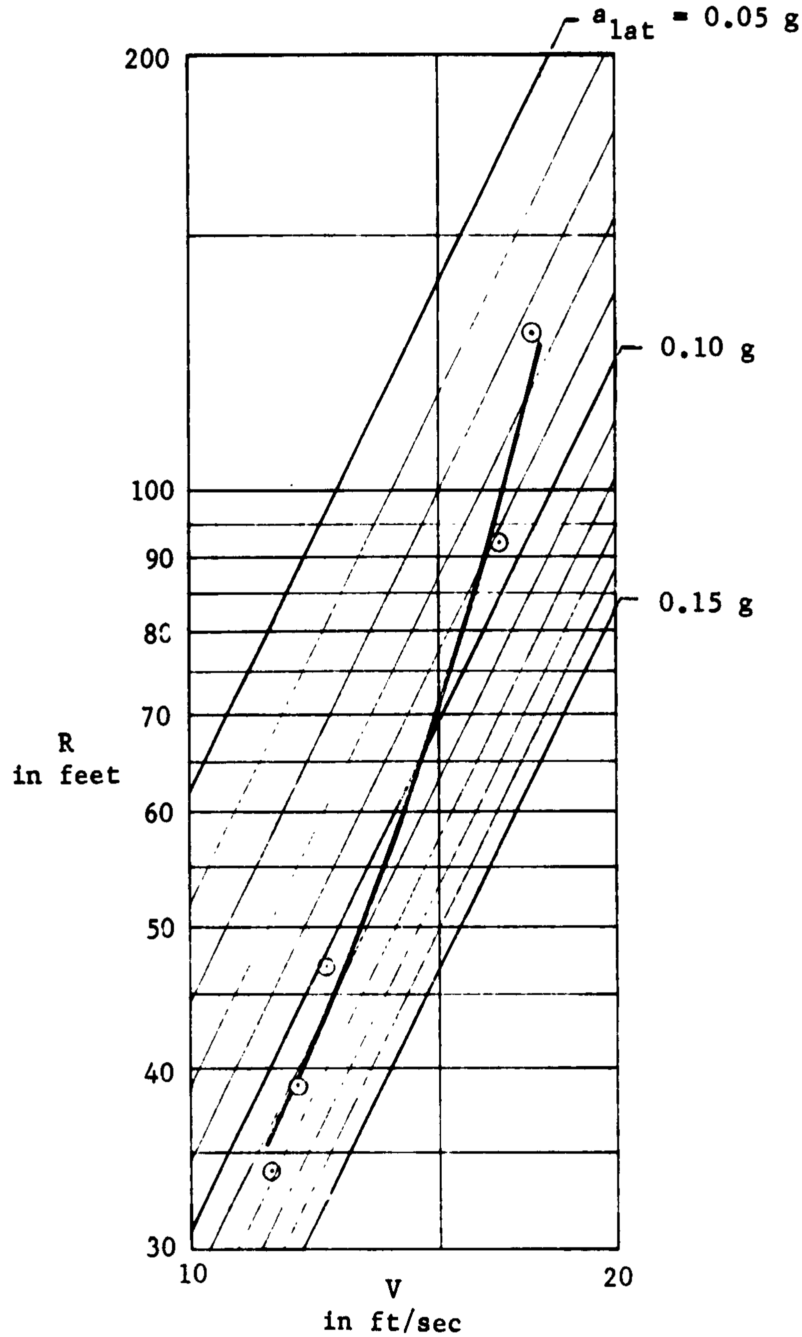


Figure 11 - Variation of Turn Radius With Speed for Steady State Turns With Full Thrust

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Tests requested by Marine Corps.

Following completion of modifications to Phase I configuration involving variable-camber vanes, spoiler flaps, cockpit armor, and bulkhead, control effectiveness tested in static test rig. After installation of fins and engine fairings, untethered tests made at low speeds to determine maximum speed and lateral acceleration. Then, reversible-pitch shrouded propeller-engine unit installed between existing nacelles for added propulsion before shipment to Langley Research Center for further testing to establish criteria for GEM flying qualities.

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GEMS--STABILITY
GEMS--PERFORMANCE
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DTMB Aero Rpt 1049

David Taylor Model Basin. Rpt 1700

PHASE II TETHERED TESTS AND LOW-SPEED FREE FLIGHT TESTS OF GEM III, by Arthur E. Johnson. Wash., Dec 1962. 17p. incl. illus. 3 refs. (Aerodynamics Lab Aero Rpt 1049. Aero Problem 630-492)

Tests requested by Marine Corps.

Following completion of modifications to Phase I configuration involving variable-camber vanes, spoiler flaps, cockpit armor, and bulkhead, control effectiveness tested in static test rig. After installation of fins and engine fairings, untethered tests made at low speeds to determine maximum speed and lateral acceleration. Then, reversible-pitch shrouded propeller-engine unit installed between existing nacelles for added propulsion before shipment to Langley Research Center for further testing to establish criteria for GEM flying qualities.

GEMS (NRA)
GEMS (MARINE CORPS 3)
GEMS--CONTROL
GEMS--STABILITY
GEMS--PERFORMANCE
FLIGHT TESTS
FLIGHT TESTS, TETHERED
SPOILERS
PROPELLERS, SHROUDED VANES, VARIABLE-CAMBER
Johnson, Arthur E
DTMB Aero Rpt 1049
DTMB Aero Test-492
Marine Corps